APPENDIX A

Network-Level Procedures

The notation LSU(update_list) represents a link-state-update message that includes the updates (u, v, c, sn) in the update_list.

```
Process_Update(i, nbr, in_message){
    // Called when an update message in_message is received from nbr.
    Update_Topology_Table(i, nbr, in_message, update_list).
    Update_Parents(i).
    For each node src in TT_i {
        Let update_list(src) consist of all tuples (k, l, c, sn) in update_list such that
        k = src.
        If update_list(src) is nonempty
            Send message LSU(update_list(src)) to children_i(src).}}

Update_Topology_Table(i, nbr, in_message, update_list){
    Set update_list to empty list.
    For each ((u,v,c,sn) in in_message) {
        If (p_i(u) == nbr) {
            If ((u,v) is in TT_i and sn > TT_i(u,v).sn) {
                Add (u,v,c,sn) to update_list.
                Set TT_i(u,v).sn = sn.
                Set TT_i(u,v).c = c.
                If (sn > sn_i(u)) Set sn_i(u) = sn.}
            If ((u,v) is not in TT_i) {
                Add (u,v,c,sn) to TT_i.
                Add (u,v,c,sn) to update_list.
                If (sn > sn_i(u)) Set sn_i(u) = sn.}}}}

Link_Change(i,j){
    // Called when the cost of link (i,j) changes.
    If (|TT_i(i,j).c - cost(i,j)|/TT_i(i,j).c > epsilon) {
        Set TT_i(i,j).c = cost(i,j).
        Set TT_i(i,j).sn = current time stamp SN_i.
        Set update_list = {(i, j, TT_i(i, j).c, TT_i(i, j).sn)
        Send message LSU(update_list) to children_i(i).}}

Link_Down(i,j){
    // Called when link (i,j) goes down.
    Remove j from N_i.
    Set TT_i(i,j).c = infinity.
```

```
        Set TT_i(i,j).sn = current time stamp SN_i.
        Update_Parents(i).
        For each (node src in TT_i) remove j from children_i(src).
        Set update_list = {(i,j, infinity, TT_i(i,j).sn)}.
        Send message LSU(update_list) to children_i(i).}

Link_Up(i,j){
        // Called when link (i,j) comes up.
        Add j to N_i.
        Set TT_i(i,j).c = cost(i,j).
        Set TT_i(i,j).sn = current time stamp SN_i.
        Update_Parents(i).
        Set update_list = {(i, j, TT_i(i,j).c, TT_i(i,j).sn)}.
        Send message LSU(update_list) to children_i(i).}

Update_Parents(i){
        Compute_New_Parents(i)
        For each (node k in N_i){
                Set cancel_src_list(k), src_list(k), and sn_list(k) to empty.}
        For each (node src in TT_i such that src != i){
                If (new_p_i(src) != p_i(src)){
                        If (p_i(src) != NULL){
                                Set k = p_i(src).
                                Add src to cancel_src_list(k).}
                        Set p_i(src) = new_p_i(src).
                        If (new_p_i(src) != NULL){
                                Set k = new_p_i(src).
                                Add src to src_list(k).
                                Add sn_i(src) to sn_list(k).}}}
        For each (node k in N_i){
                If (src_list(k) is nonempty){
                        Send message NEW PARENT(src_list(k), sn_list(k)) to k.}
                If (cancel_src_list(k) is nonempty{
                        Send message CANCEL PARENT(cancel_src_list(k)) to k.}}}

Compute_New_Parents(i){
        For each (node src in TT_i such that src != i){
                Set new_p_i(src) = NULL.}
        Compute min-hop paths using Dijkstra.
        For each (node src in TT_i such that src != i){
                Set new_p_i(src) equal to the neighbor of node i along the minimum-hop
                path from i to src.}}

Process_New_Parent(i, nbr, src_list, sn_list){
        // Called when node i receives a NEW PARENT(src_list, sn_list) message from
        nbr.
        Set update_list to empty list.
```

```
        For each (node src in src_list) {
                Let sn_list.src denote the sequence number corresponding to src in sn_list.
                Add nbr to children_i(src).
                Set new_updates = {(k, l, c, sn) in TT_i such that k = src and sn >
                sn_list.src}.
                Add new_updates to update_list.}
        Send message LSU(update_list) to nbr.}

    Process_Cancel_Parent(i,nbr,src_list ){
        // Called when node i receives a CANCEL PARENT(src_list) message from nbr.
        For each (node src in src_list) remove nbr from children_i(src).}

    Send_Periodic_Updates(i){
        Set update_list to empty.
        For each (j in N_i such that TT_i(i,j). c != infinity){
                Set TT_i(i,j).sn = current time stamp SN_i.
                Add (i, j, TT_i(i,j).c, TT_i(i,j).sn) to update_list. }
        Send message LSU(update_list) to children_i(i).}

    Compute_New_Parents2(i){
        S ← ∅;
        For each (v ∈ TT_i) {
                Set d(v) = infinity;
                Set pred(v) = NULL;
                Set new_p_i(v) = NULL; }
        d(i) ← 0;
        While (there exists w ∈ TT_i – S such that d(w) < infinity){
                Set u = node w ∈ TT_i – S that minimizes d(w);
                Set S = S ∪ {u};
                For each (v such that (u, v) ∈ TT_i) {
                        If (d(u) + 1 < d(v) or [d(u) + 1 = d(v) and new_p_i(u) = p_i(v)]) {
                                Set d(v) = d(u) + 1;
                                Set pred(v) = u;
                                If (u = i)  Set new_p_i(v) = v;
                                Else Set new_p_i(v) = new_p_i(u); }}}}
```

Partial-Topology 1

The function Mark_Special_Links() is called whenever the parent p_i(src) or the set of children children_i(src) for any source src changes. The notation LSU(update_list) represents a link-state-update message that includes the updates (u, v, c, sn, sp) in the update_list, where sp is

a single bit that indicates whether the link is "special", i.e., whether it should be broadcast to all nodes.

```
Mark_Special_Links(i){
    For all (outgoing links (i,j)) {Set TT_i(i,j).sp = 0;}
    For all (nodes src != i){
        if (p_i(src) != NULL and p_i(src) != src){
            Set TT_i(i, p_i(src)).sp = 1;}   //Link is special.
            For all (nodes j in children_i(src)){
                Set TT_i(i,j).sp = 1;}   //Link is special.
    }
}

Update_Topology_Table(i, nbr, in_message, update_list){
    Set update_list to empty list.
    For each ((u,v,c,sn,sp) in in_message) {
        If (p_i(u) = nbr) {
            If ((u,v) is in TT_i and sn > TT_i(u,v).sn) {
                Set TT_i(u,v).sn = sn.
                Set TT_i(u,v).c = c.
                Set TT_i(u,v).sp = sp.
                (Only links marked as special are forwarded.)
                If (sp = 1) Add (u,v,c,sn,sp) to update_list.
                If (sn > sn_i(u)) Set sn_i(u) = sn.}
            If ((u,v) is not in TT_i) {
                Add (u,v,c,sn,sp) to TT_i.
                If (sp = 1) Add (u,v,c,sn,sp) to update_list.
                If (sn > sn_i(u)) Set sn_i(u) = sn.}}}}

Process_Update(i, nbr, in_message){
    // Called when an update message in_message is received from nbr.
    Update_Topology_Table(i, nbr, in_message, update_list).
    Update_Parents(i).
    Mark_Special_Links(i).
    For each node src in TT_i {
        Let update_list(src) consist of all tuples (k, l, c, sn, sp) in update_list such
        that k = src.
        If update_list(src) is nonempty
            Send message LSU(update_list(src)) to children_i(src).}}

Link_Change(i,j){
    // Called when the cost of link (i,j) changes.
    If (|TT_i(i,j).c - cost(i,j)|/TT_i(i,j).c > epsilon) {
        Set TT_i(i,j).c = cost(i,j).
        Set TT_i(i,j).sn = current time stamp SN_i.
```

```
                Set update_list = {(i, j, TT_i(i, j).c, TT_i(i, j).sn, TT_i(i,j).sp)}.
                Send message LSU(update_list) to children_i(i).}}

Link_Down(i,j){
        // Called when link (i,j) goes down.
        Remove j from N_i.
        Set TT_i(i,j).c = infinity.
        Set TT_i(i,j).sn = current time stamp SN_i.
        Update_Parents(i).
        For each (node src in TT_i) remove j from children_i(src).
        Mark_Special_Links(i).
        Set update_list = {(i,j, infinity, TT_i(i,j).sn, TT_i(i,j).sp)}.
        Send message LSU(update_list) to children_i(i).}

Link_Up(i,j){
        // Called when link (i,j) comes up.
        Add j to N_i.
        Set TT_i(i,j).c = cost(i,j).
        Set TT_i(i,j).sn = current time stamp SN_i.
        Update_Parents(i).
        Mark_Special_Links(i).
        Set update_list = {(i, j, TT_i(i,j).c, TT_i(i,j).sn, TT_i(i,j).sp)}.
        Send message LSU(update_list) to children_i(i).}

Update_Parents(i){
        Compute_New_Parents(i).
        For each (node k in N_i)
                Set cancel_src_list(k), src_list(k), and sn_list(k) to empty.
        For each (node src in TT_i such that src != i){
                If (new_p_i(src) != p_i(src)){
                        If (p_i(src) != NULL){
                                Set k = p_i(src).
                                Add src to cancel_src_list(k).}
                        Set p_i(src) = new_p_i(src).
                        If (new_p_i(src) != NULL){
                                Set k = new_p_i(src).
                                Add src to src_list(k).
                                Add sn_i(src) to sn_list(k).}}}
        For each (node k in N_i){
                If (src_list(k) is nonempty){
                        Send message NEW PARENT(src_list(k), sn_list(k)) to k.}
                If (cancel_src_list(k) is nonempty{
                        Send message CANCEL PARENT(cancel_src_list(k)) to k.}}}

Compute_New_Parents(i){
        For each (node src in TT_i such that src != i){
                Set new_p_i(src) = NULL.}
```

```
        Compute min-hop paths using Dijkstra.
        For each (node src in TT_i such that src != i){
            Set new_p_i(src) equal to the neighbor of node i along the minimum-hop
            path from i to src.}}

    Process_New_Parent(i, nbr, src_list, sn_list){
        //Called when node i receives a NEW PARENT(src_list, sn_list) message from
        nbr.
        Set update_list to empty list.
        For each (node src in src_list) {
            Let sn_list.src denote the sequence number corresponding to src in sn_list.
            Add nbr to children_i(src).
            If (src != i) Set TT_i(i, nbr).sp = 1.  //Link to nbr is special.
            If (src = i)  Set new_updates = {(src, v, c, sn, sp) in TT_i such that
                    sn > sn_list.src}.
            If (src != i) Set new_updates = {(src, v, c, sn, sp) in TT_i such that
                    sn > sn_list.src and sp = 1}.  //Only special links are sent.
            Add new_updates to update_list.}
        Send message LSU(update_list) to nbr.}

    Process_Cancel_Parent(i,nbr,src_list ){
        // Called when node i receives a CANCEL PARENT(src_list) message from nbr.
        For each (node src in src_list) remove nbr from children_i(src).
        Mark_Special_Links(i). }

    Send_Periodic_Updates(i){
        Set update_list to empty.
        For each (j in N_i such that TT_i(i,j).c != infinity){
            Set TT_i(i,j).sn = current time stamp SN_i.
            Add (i, j, TT_i(i,j).c, TT_i(i,j).sn, TT_i(i,j).sp) to update_list. }
        Send message LSU(update_list) to children_i(i).}
```

Partial-Topology 2

```
    Update(i, k, in_message){
        Update_Topology Table(i, k, in_message);
        Lex_Dijkstra;  // Uses lexicographic Dijkstra to compute Ti
        Generate_Updates(i, update_list);
        if (k does not equal i and update_list is non-empty){
            Send_Updates_Children(i, update_list);
        Update_Parents(i);
    }

    Send_Updates_Children(i, update_list){
        For each (node k ∈ Ni) {out_message(k) ← 0;}
        For each (node src ∈ TT_i s.t. src does not equal i){
            update_list(src) ← {(k, l, c) ∈ update_list s.t. k = src};
```

```
                for each (node k ∈ children_i(src)){
                        Add update_list(src) to out_message(k);}
        }
        For each (node k ∈ Ni s.t. out_message(k) is non-empty){
                Send the message out_message(k) to node k;}
}

Update_Topology_Table(i, k, in_message){
        For each ((u, v, c) ∈ in_message{
                // Process only updates received from the parent p_i(u)
                if (p_i(u) = k or k = i){
                        if ((u, v)∉ TT_i or c! = TT_i(u, v).c{
                                TT_i(u, v) ← (u, v, c);
                                Mark (u, v) as changed in TT_i;}
                }
        }
        if (in_message is a PARENT_RESPONSE){
                For each (u such that in_message includes source u){
                        if (p_i(u) = k and pending_i(u) = 1){
                                pending_i(u) = 0;
                                For each (v such that TT_i contains an entry for (u, v)){
                                        if (in_message does not contain update for link (u,
                                        v)){
                                                TT_i(u, v).c ←∞;
                                                // indicates link should be deleted
                                                Mark (u, v) as changed in TT_i;
                                        }
                                }
                        }
                }
        }
}

Process_Cancel_Parent(i, nbr, src_list){
        For each (src ∈ src_list)
                children_i(src) ← children_i(src) – {nbr};
}

Generate_Updates(i, update_list){
        update_list ← 0;
        for each (entry (u, v, c, c') ∈ TT_i){
                if ((u, v) is in new Ti and ((u, v) is marked as changed or is not in old
                Ti)){
                        Add (u, v, c) to update_list;
                        Ti(u, v).c' ← Ti(u, v).c;
                        Ri ← Ri ∪{(u, v)};
```

```
                }
                else if ((u, v) is in Ri but not in new Ti and c > c'){
                        Add (u, v, ∞) to update_list;  // delete update
                        Ti(u, v).c' ← ∞;
                        Remove (u, v) from Ri;
                }
                if (TT_i(u, v).c = ∞)
                        Remove (u, v) from TT_i;
        }
}

Update_Parents(i){
        For each (node k ∈ Ni){
                cancel_src_list(k) ← 0;
                src_list(k) ← 0;}
        For each (node src ∈TT_i such that src ≠ i) {
                new_p_i(src) ← next node on shortest path to src;
                if (new_p_i(src) ≠p_i(src)){
                        if (new_p_i(src) ≠ NULL) {
                                k ← p_i(src);
                                cancel_src_list(k) ← cancel_src_list(k) ∪ {src};
                        }
                        if (new_p_i(src) ≠ NULL){
                                k ← new_p_i(src);
                                src_list(k) ← src_list(k) ∪ {src};
                        }
                        p_i(src) ← new_p_i(src);
                }
        }
        For each (node k ∈ Ni){
                if (src_list(k) ≠ 0)
                        Send NEW_PARENT(src_list(k)) to node k;
                if(cancel_src_list(k) ≠ 0)
                        Send CANCEL_PARENT(cancel_src_list(k)) to node k;
        }
}

Process_New_Parent(i, nbr, src_list){
        update_list ← 0;
        for each (node u ∈ u_list) {
                children_i(u) ← children_i(u) ∪ {nbr};
                updates(u) ← {(u, v, c) ∈ TT_i such that (u, v) ∈ Ti};
                update_list ← update_list ∪ updates (u);
        }
        Send PARENT RESPONSE(src_list, update_list) to nbr;}
```